CIE USNC CNC Joint Meeting, NIST, Oct. 3, 2017

Vision Experiment II on Chroma Saturation Preference in Different Hues

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Shortcomings of CRI

Scientific inaccuracies as a color fidelity metric

- Outdated color space (W*U*V*)
- Outdated chromatic adaptation transform (von Kries)
- Small number of test samples (8) can cause anomalies.
- Reference illuminant moves with that of test light source of any CCT

Problem of color fidelity metrics

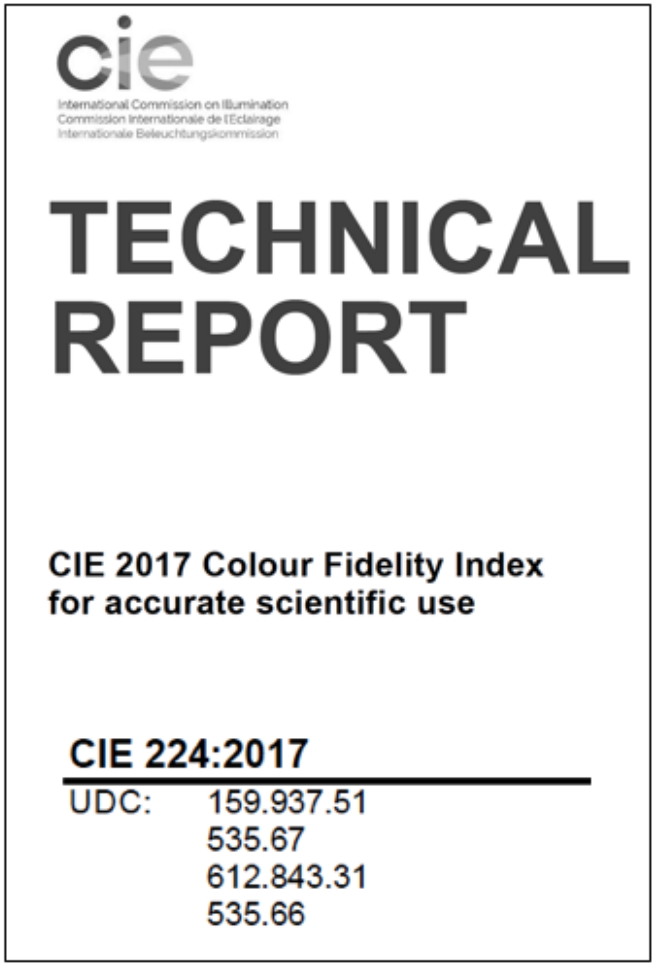
- CRI is designed as a color fidelity metric (with respect to a reference illuminant.) → It does not address effects of perception/preference.

The users of lighting expect CRI to work as an overall color quality measure.

CIE 224:2017

CIE 2017 Colour Fidelity Index

for Accurate Scientific Use


cie
International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

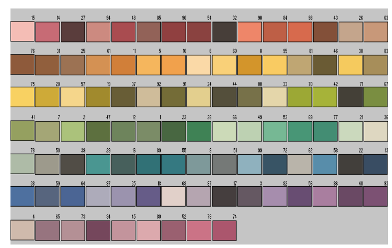
TECHNICAL REPORT

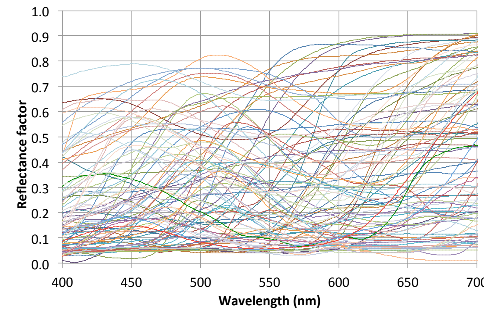
CIE 2017 Colour Fidelity Index for accurate scientific use

CIE 224:2017

UDC: 159.937.51
535.67
612.843.31
535.66

- Published April 2017.
- It is based on Fidelity Index R_f in IES TM-30, using the same 99 test samples, the same formulae. A few small changes.





- "The general colour fidelity index R_f is not a replacement of the CRI (R_a) for the purpose of rating and specification of products nor for regulatory or other minimum performance requirements"

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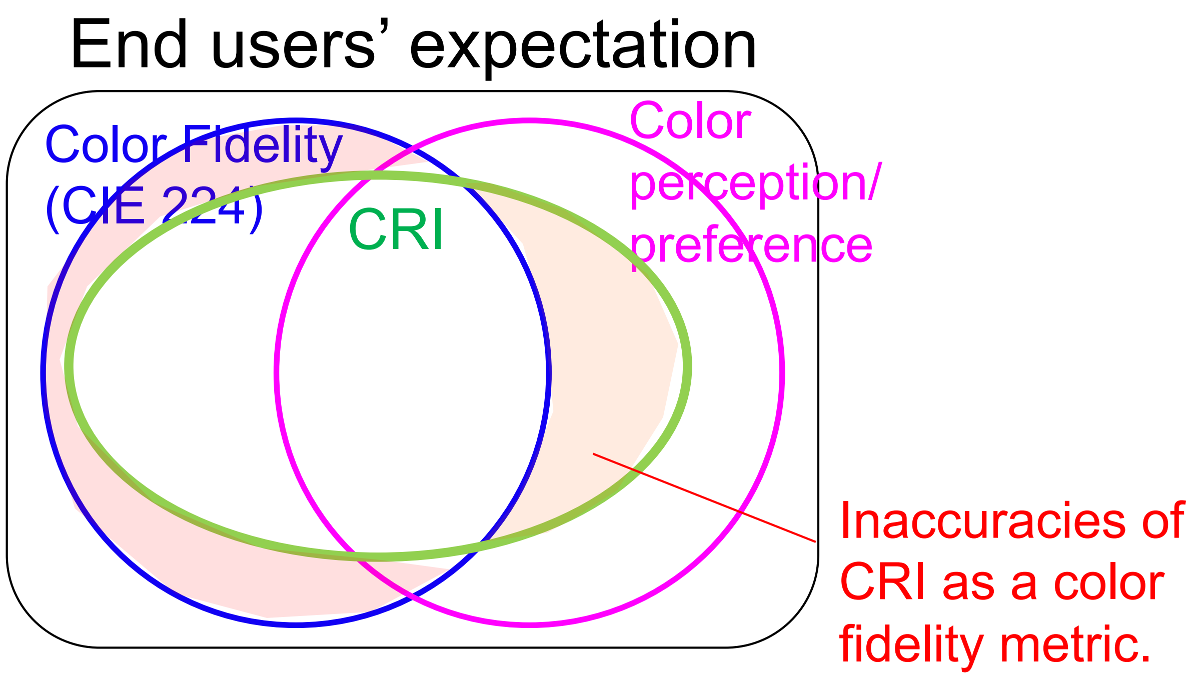
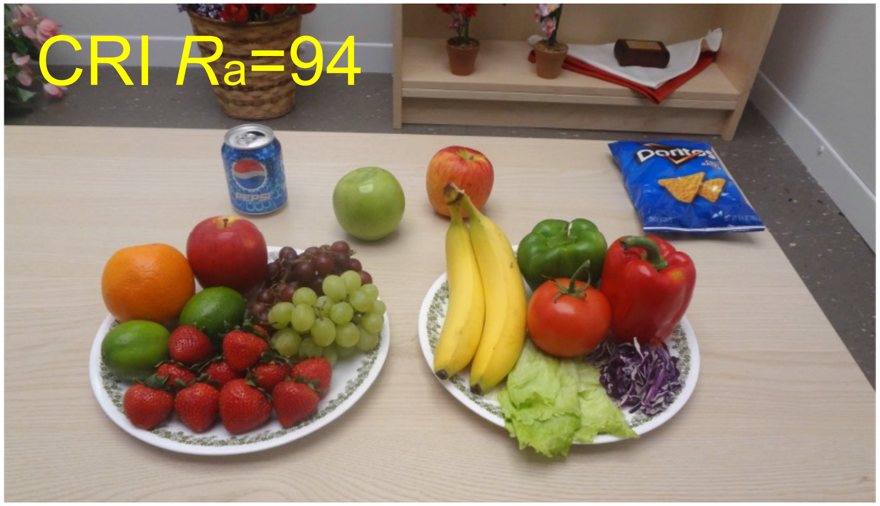
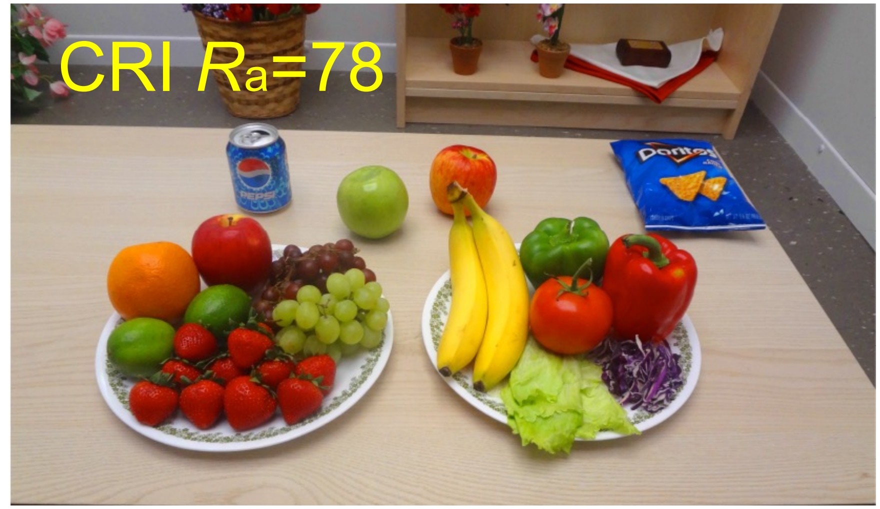
Overall Color Quality



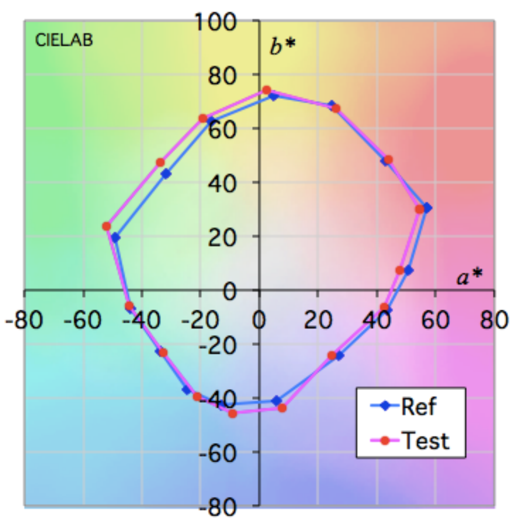
Why perception differs from the CRI scores?





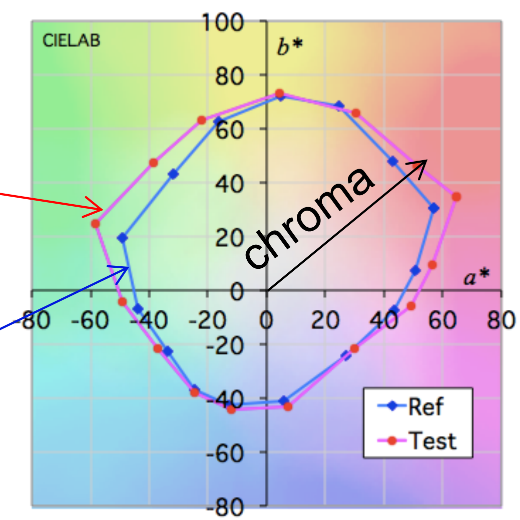
Plots of 15 CQS samples on CIELAB (a*,b*)

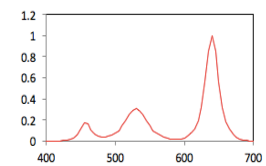
The size of plot area is “**Gamut area**”

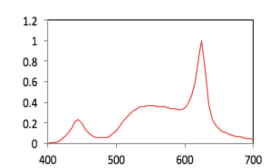


Test light (R_a=78)

Reference (Planckian)







- **CRI is penalizing good, preferred light sources!**

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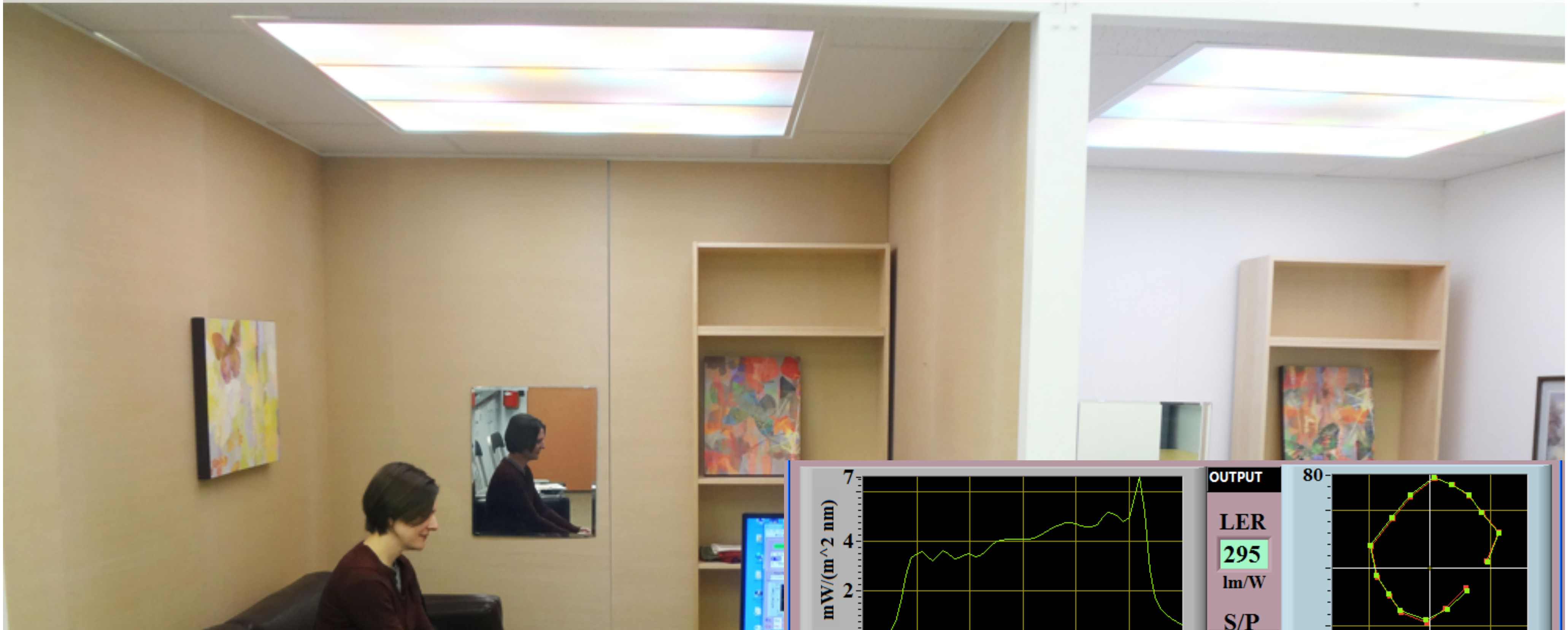
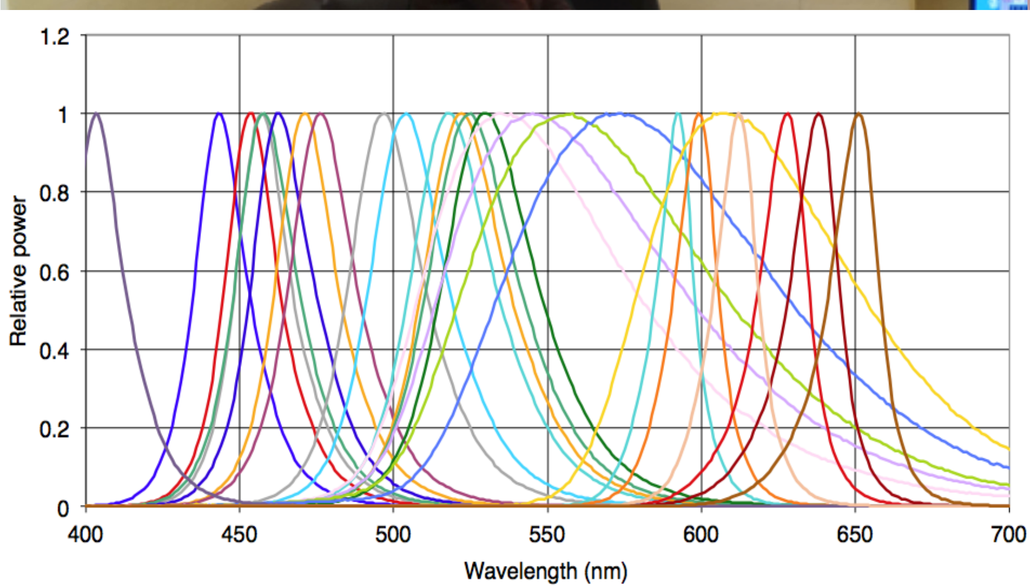
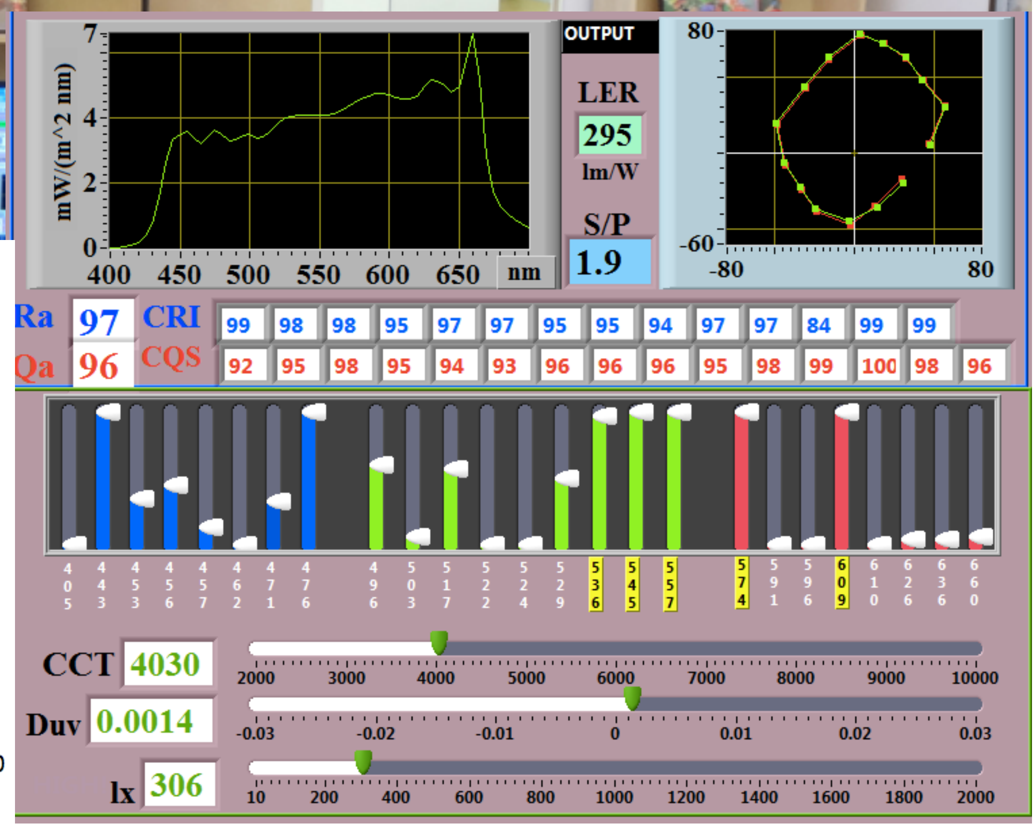
NIST Spectrally Tunable Lighting Facility

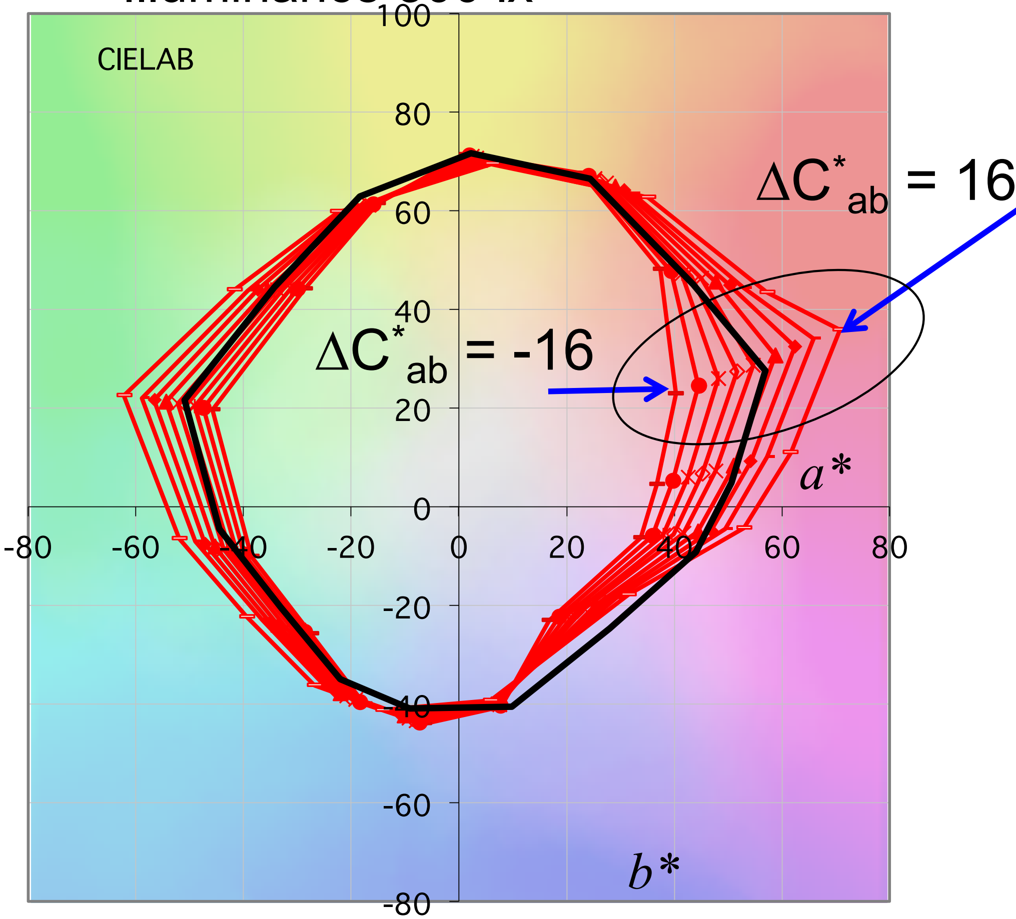






2014 Vision Experiment at NIST on preferred chroma saturation level

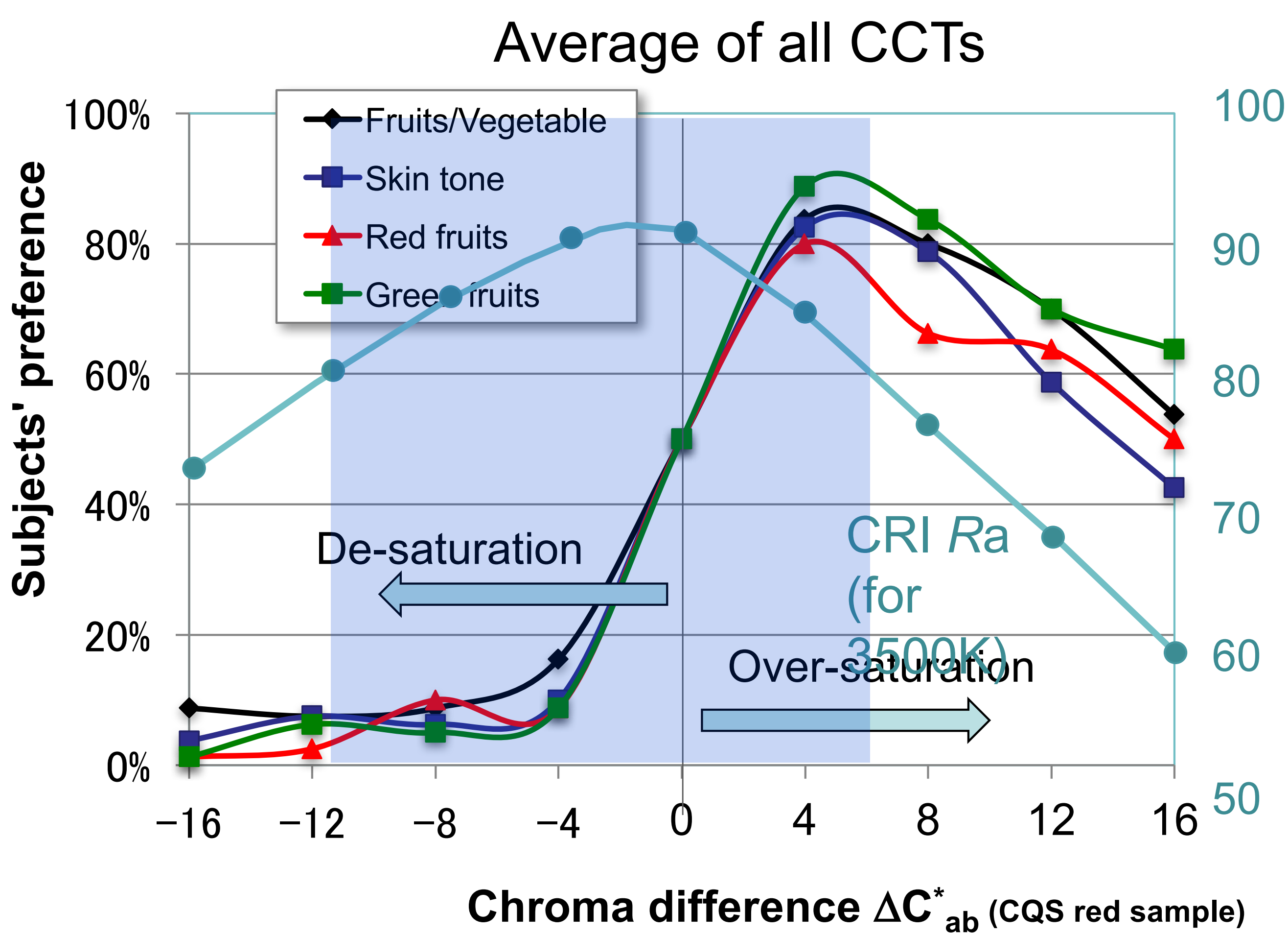
- 20 subjects
- 2700 K, 3500 K, 5000 K
- D_{uv}=0, -0.015 (3500 K only)
- Illuminance 300 lx



Most saturated

Most de-saturated

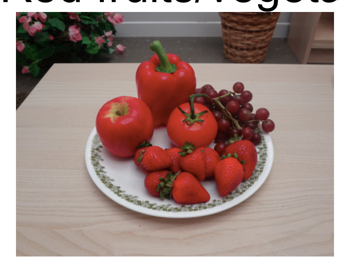
Results of 2014 experiment



(1) Entire room

(2) Skin tone of subject

(3) Red fruits/vegetables

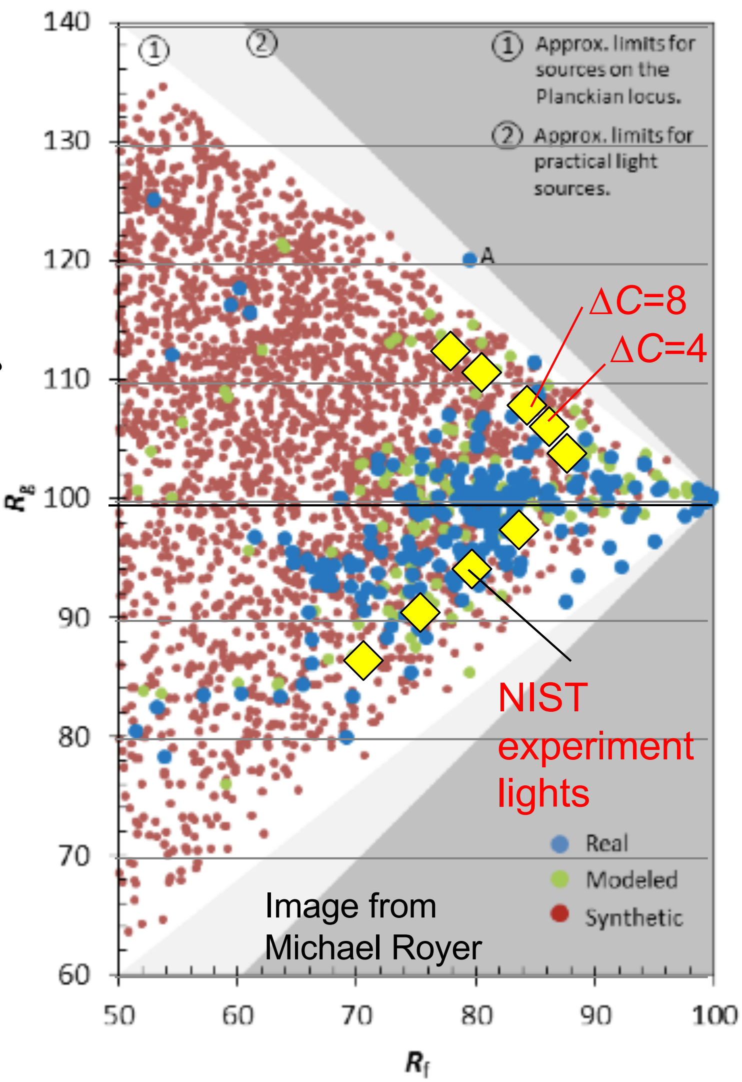


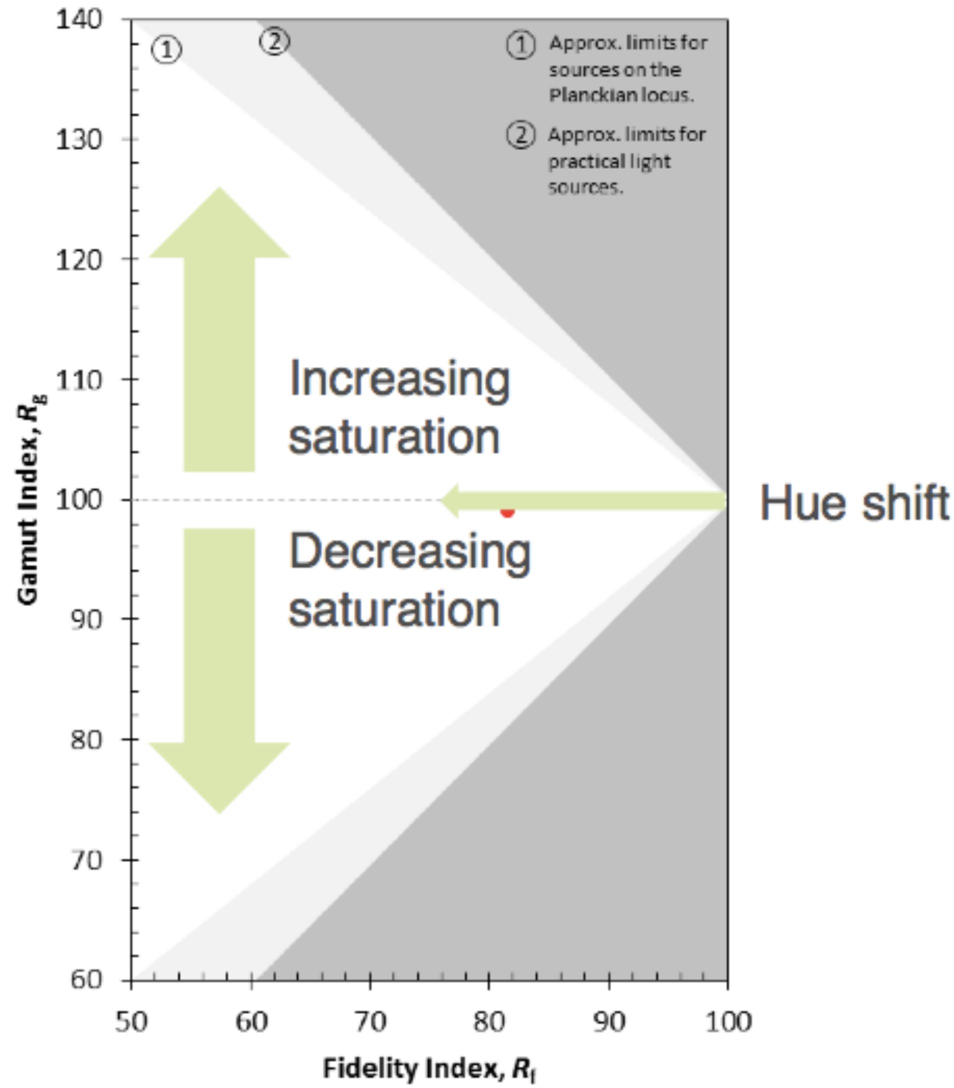
(4) Green fruits/vegetables

Reference: Y. Ohno, M. Fein, C. Miller, Vision Experiment on Chroma Saturation for Color Quality Preference, CIE 216 :2015, pp. 60 – 69 (2015)

IES TM-30 Concept of a Two-Metric System

Gamut R_g





Fidelity R_f

Image from Michael Royer.

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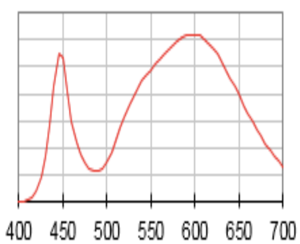
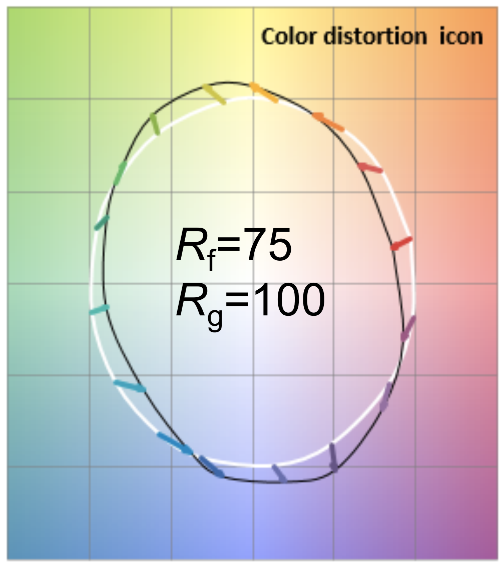
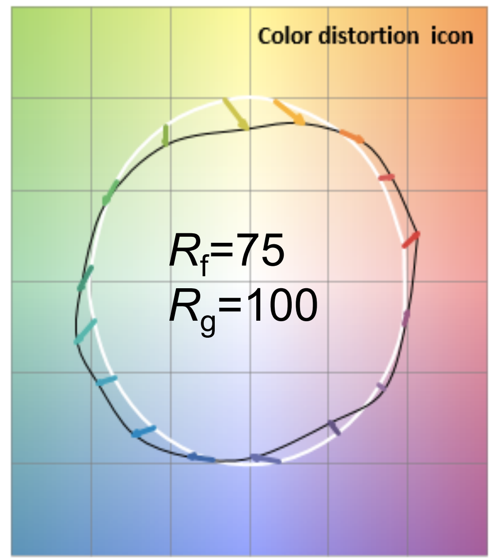
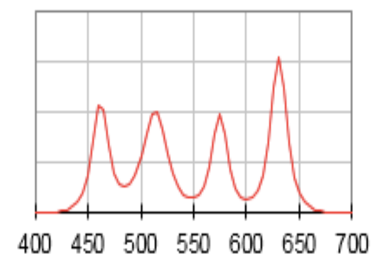
Gamut area is not sufficient

R_g (Gamut Index) is equal but gamut shapes are different.









Looks better

Perceived color quality of these two lights are very different.

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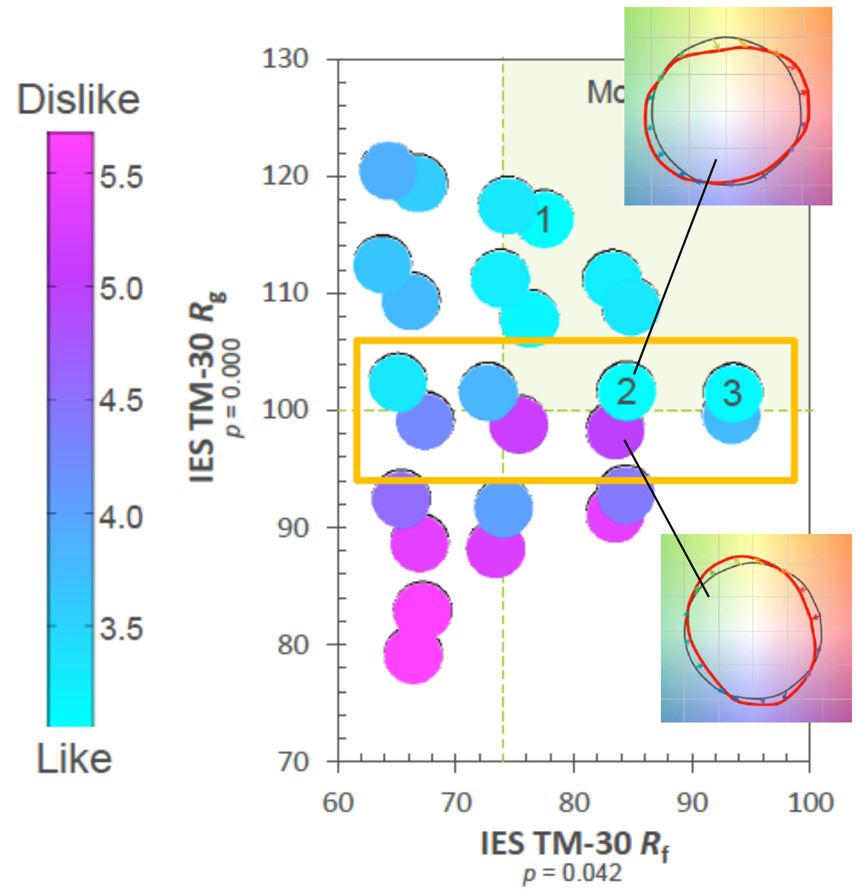
Other Study – by Michael Royer, PNNL

Experimental Room

Experimental Room: Context

Lighting Conditions: 26
Illuminance: 20 fc
CCT: 3500 K (on Planckian)
Objects: Generic consumer goods, balanced hues
Application: Undefined
Participants: 19-65, 16 females 12 males
Rating Questions: Normal-Shifted, Saturated-Dull, Like-Dislike



Sides from Michael Royer, Energy Star Webinar, March 31, 2016

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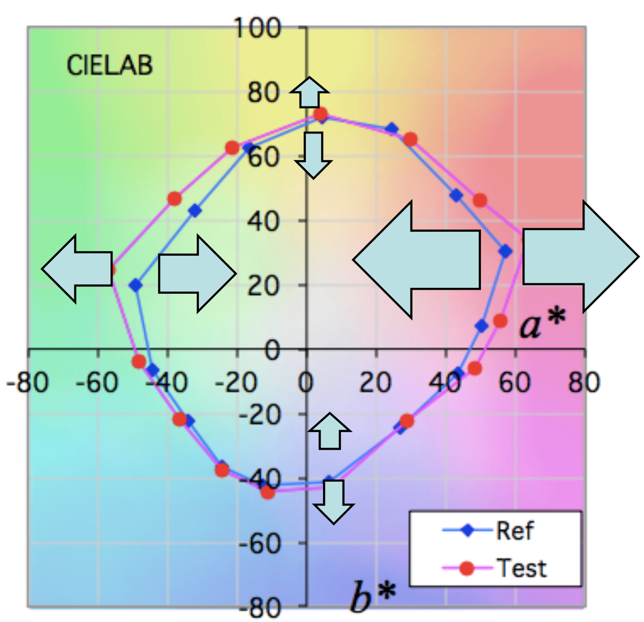
Color preference depends on gamut shape, on chroma shift in different hues

Hypothesis



Goal: Develop a preference perception model.

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NIST 2016-2017 experiments on color saturation preference in different hues

Color saturation / de-saturation:
Which color (hue) is most critical in affecting preference?

2016: 19 subjects
2017: 23 subjects

Targets:
- Fruits/vegetables

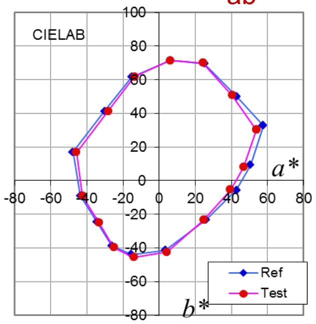
2700 K (Duv = 0)
3500 K (Duv = 0) 2017
5000 K (Duv = 0)
3500 K (Duv= - 0.015)

- Skin tone 2017

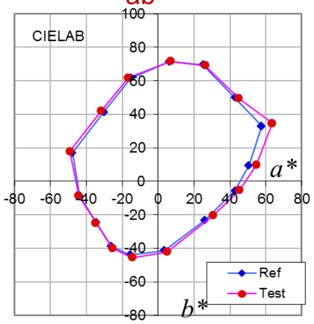
3500 K (Duv = 0)

Gamut shapes (3500 K)

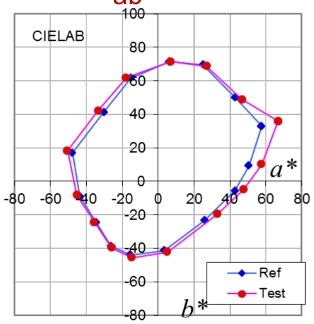
Red ΔC^*_{ab}=-5



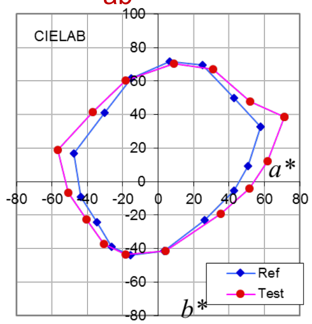
ΔC^*_{ab}=5



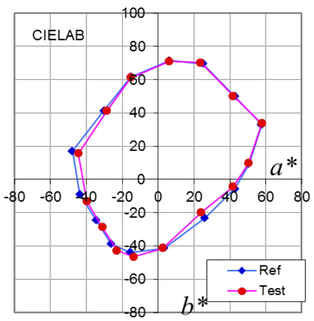
ΔC^*_{ab}=10



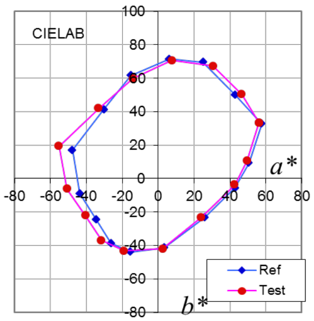
ΔC^*_{ab}=15



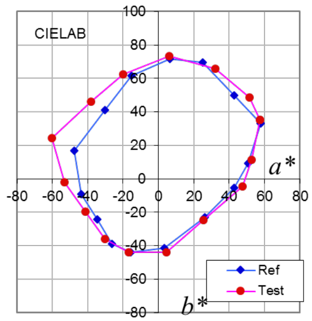
Green ΔC^*_{ab}=-5



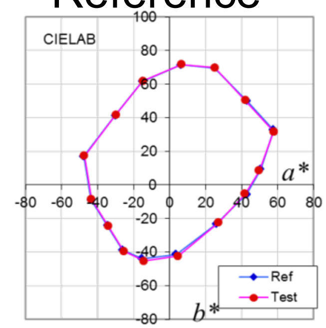
ΔC^*_{ab}=10



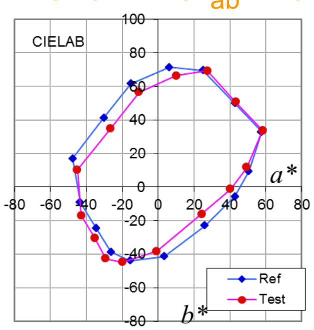
ΔC^*_{ab}=15



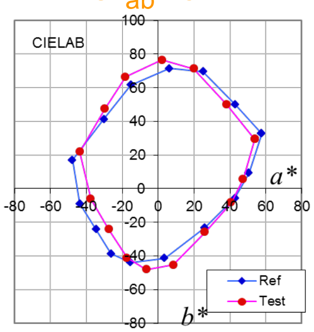
Reference



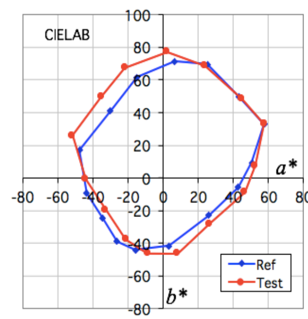
Yellow ΔC^*_{ab}= -5



ΔC^*_{ab}=5



Y-G ΔC^*_{ab}=10



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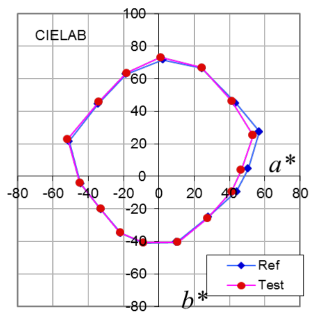
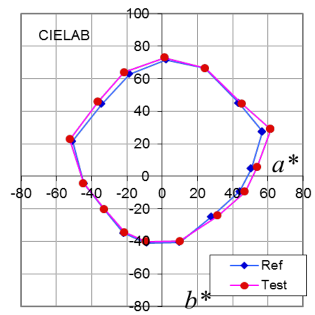
Gamut shapes (5000 K)

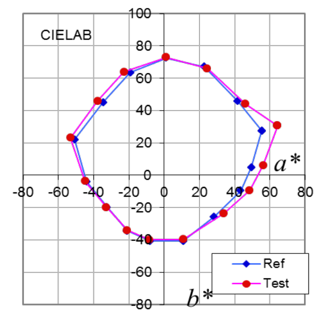
Red ΔC^*_{ab}=-5



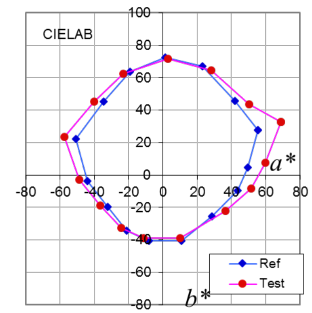
ΔC^*_{ab}=5



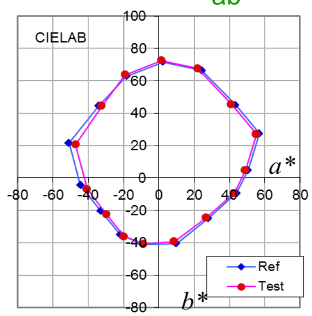
ΔC^*_{ab}=10



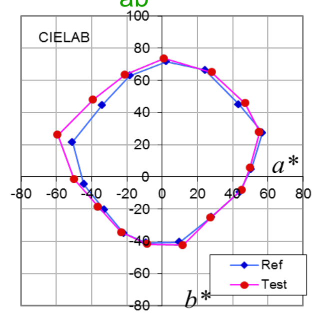
ΔC^*_{ab}=+15



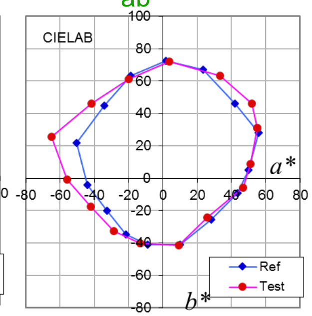
Green ΔC^*_{ab}=-5



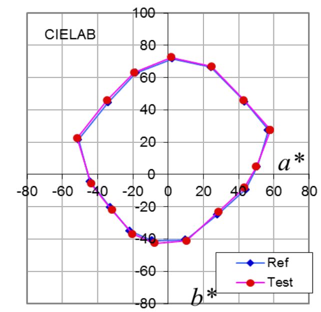
ΔC^*_{ab}=10



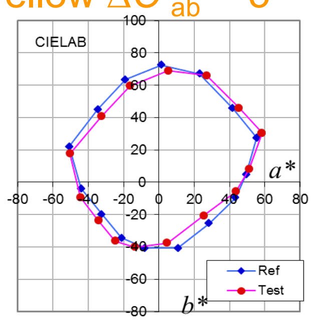
ΔC^*_{ab}=15



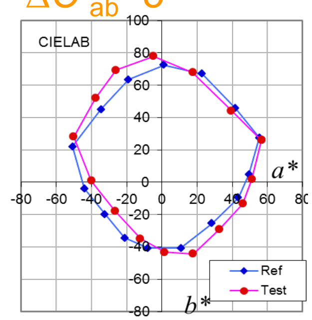
Reference



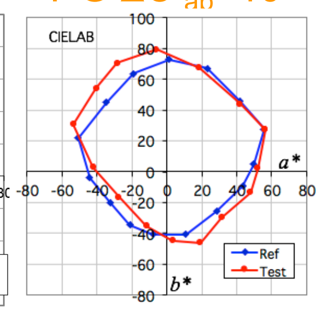
Yellow ΔC^*_{ab}= -5



ΔC^*_{ab}=5



Y-G ΔC^*_{ab}=10



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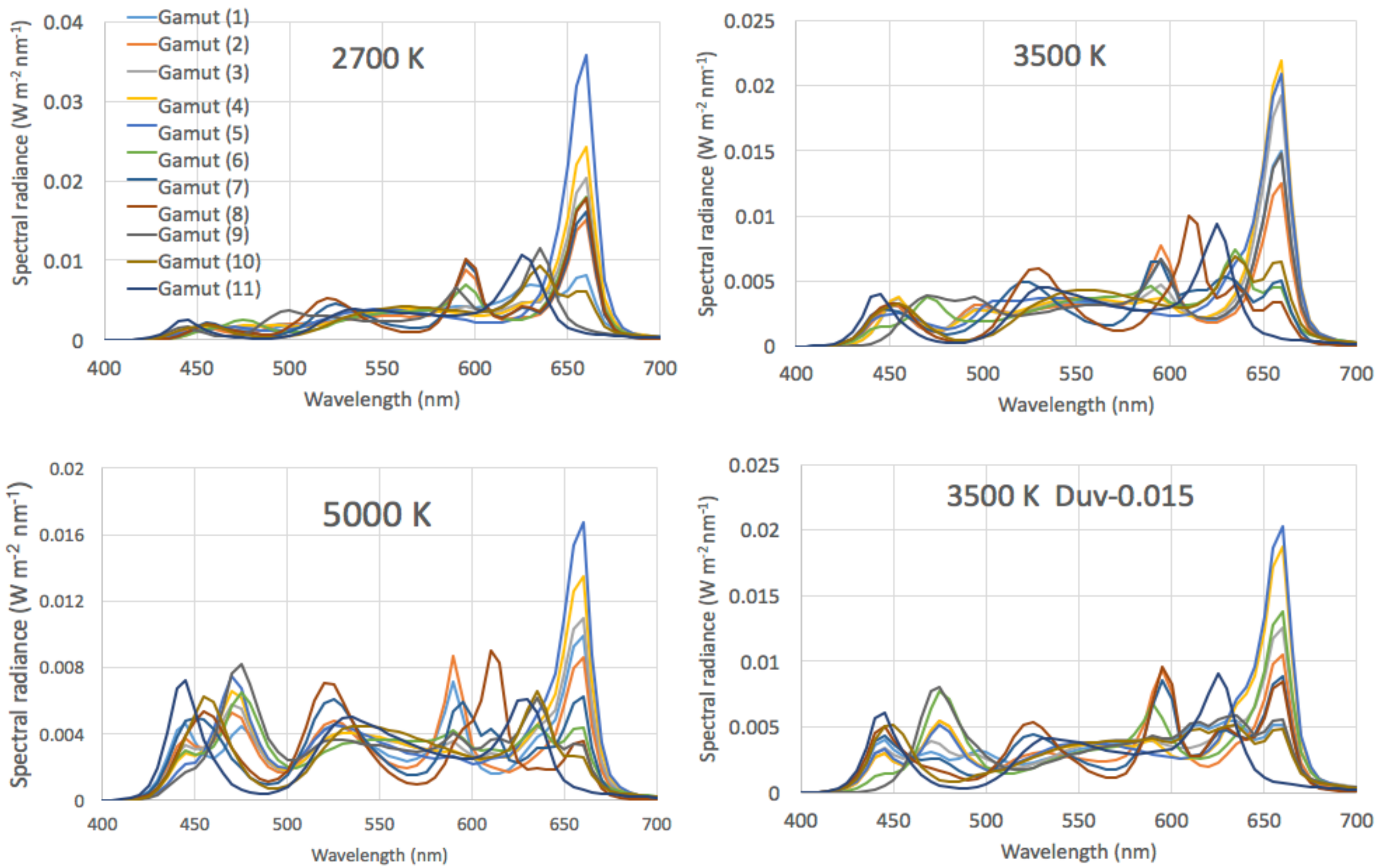
Spectra



Gamut (1)
Gamut (2)
Gamut (3)
Gamut (4)
Gamut (5)
Gamut (6)
Gamut (7)
Gamut (8)
Gamut (9)
Gamut (10)
Gamut (11)
2700 K
3500 K
5000 K
3500 K Duv-0.015
Spectral radiance (W m-2 nm-1)
Wavelength (nm)
0
0.01
0.02
0.03
0.04
0.005
0.015
0.025
0.004
0.008
0.012
0.016
400
450
500
550
600
650
700

Comparison of pairs
(all combinations of the 11 lights)

	1	2	3	4	5	6	7	8	9	10	11
1											
2	A or B										
3											
4											
5											
6											
7											
8											
9											
10											
11											

Pair	A	B
1	3	5
2	9	4
3	1	4
..	..	..
..	..	..
55	10	11

"A"

"B"

Number of subjects who selected i over j

1) Raw Data

$j \setminus i$	1	2	3	4	5	6	7	8	9	10	11
1											
2	17										
3	2	3									
4	2	2	4								
5	5	6	7	8							
6	14	7	15	17	15						
7	7	1	12	13	14	6					
8	3	3	9	10	12	3	3				
9	11	8	16	16	15	11	12	16			
10	9	3	13	15	13	6	9	15	8		
11	6	3	14	13	12	9	10	15	10	11	

*Each cell represents the number of responds preferring the lighting on 'Column' side

2) Proportion $p_{i,j}$

	1	2	3	4	5	6	7	8	9	10	11
1	0.50	0.11	0.89	0.89	0.74	0.26	0.63	0.84	0.42	0.53	0.68
2	0.89	0.50	0.84	0.89	0.68	0.63	0.95	0.84	0.58	0.84	0.84
3	0.11	0.16	0.50	0.79	0.63	0.21	0.37	0.53	0.16	0.32	0.26
4	0.11	0.11	0.21	0.50	0.58	0.11	0.32	0.47	0.16	0.21	0.32
5	0.26	0.32	0.37	0.42	0.50	0.21	0.26	0.37	0.21	0.32	0.37
6	0.74	0.37	0.79	0.89	0.79	0.50	0.68	0.84	0.42	0.68	0.53
7	0.37	0.05	0.63	0.68	0.74	0.32	0.50	0.84	0.37	0.53	0.47
8	0.16	0.16	0.47	0.53	0.63	0.16	0.16	0.50	0.16	0.21	0.21
9	0.58	0.42	0.84	0.84	0.79	0.58	0.63	0.84	0.50	0.58	0.47
10	0.47	0.16	0.68	0.79	0.68	0.32	0.47	0.79	0.42	0.50	0.42
11	0.32	0.16	0.74	0.68	0.63	0.47	0.53	0.79	0.53	0.58	0.50

3) Z-score $z_{i,j}$

	1	2	3	4	5	6	7	8	9	10	11
1	0.00	-1.25	1.25	1.25	0.63	-0.63	0.34	1.00	-0.20	0.07	0.48
2	1.25	0.00	1.00	1.25	0.48	0.34	1.62	1.00	0.20	1.00	1.00
3	-1.25	-1.00	0.00	0.80	0.34	-0.80	-0.34	0.07	-1.00	-0.48	-0.63
4	-1.25	-1.25	-0.80	0.00	0.20	-1.25	-0.48	-0.07	-1.00	-0.80	-0.48
5	-0.63	-0.48	-0.34	-0.20	0.00	-0.80	-0.63	-0.34	-0.80	-0.48	-0.34
6	0.63	-0.34	0.80	1.25	0.80	0.00	0.48	1.00	-0.20	0.48	0.07
7	-0.34	-1.62	0.34	0.48	0.63	-0.48	0.00	1.00	-0.34	0.07	-0.07
8	-1.00	-1.00	-0.07	0.07	0.34	-1.00	-1.00	0.00	-1.00	-0.80	-0.80
9	0.20	-0.20	1.00	1.00	0.80	0.20	0.34	1.00	0.00	0.20	-0.07
10	-0.07	-1.00	0.48	0.80	0.48	-0.48	-0.07	0.80	-0.20	0.00	-0.20
11	-0.48	-1.00	0.63	0.48	0.34	-0.07	0.07	0.80	0.07	0.20	0.00
Average	-0.27	-0.83	0.39	0.65	0.46	-0.45	0.03	0.57	-0.41	-0.05	-0.09

For all subjects

$z_{i,j}$ = NORM.S.INV ($p_{i,j}$)

Inverse of the standard normal cumulative distribution.

The distribution has a mean of zero and a standard deviation of one.

NORM.S.INV function

For a probability density function of the standard normal distribution

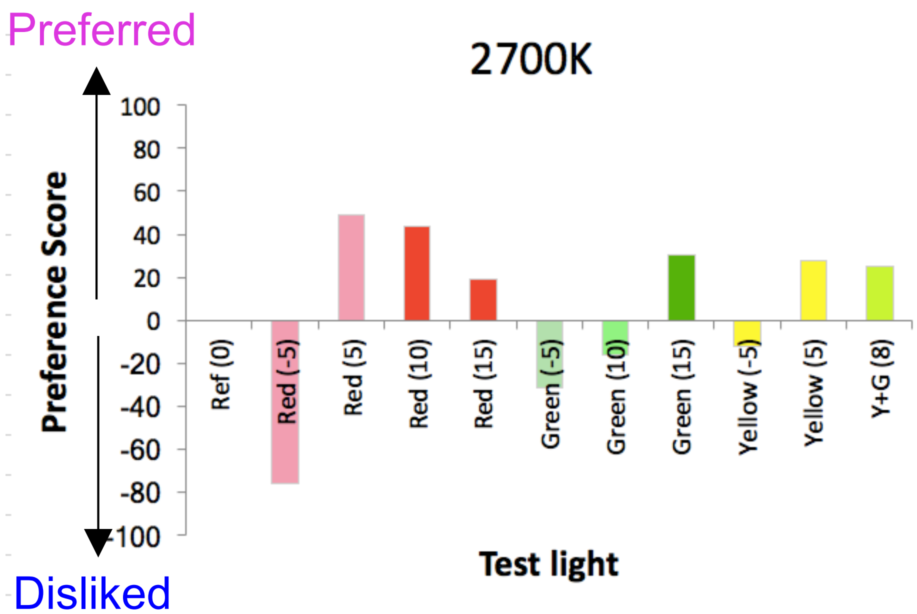
$$f(x) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right)$$

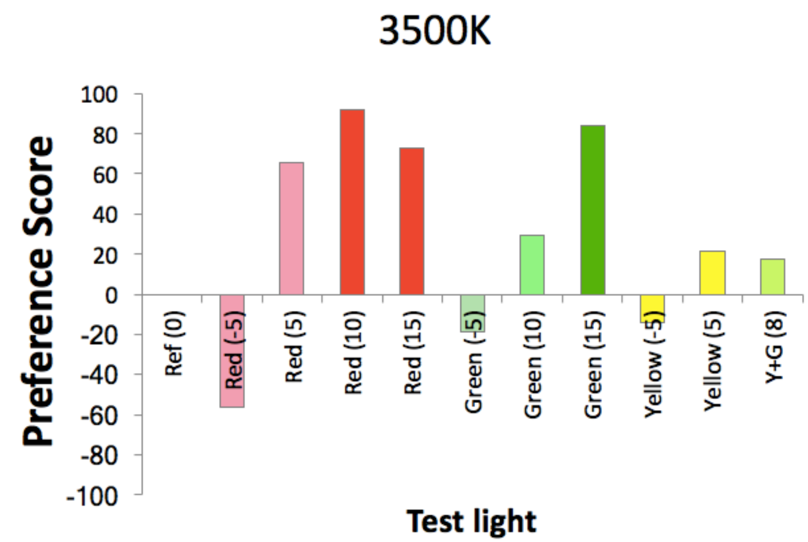
$$z_{ij} = x; \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right) \mathrm{d}x = p_{ij}$$

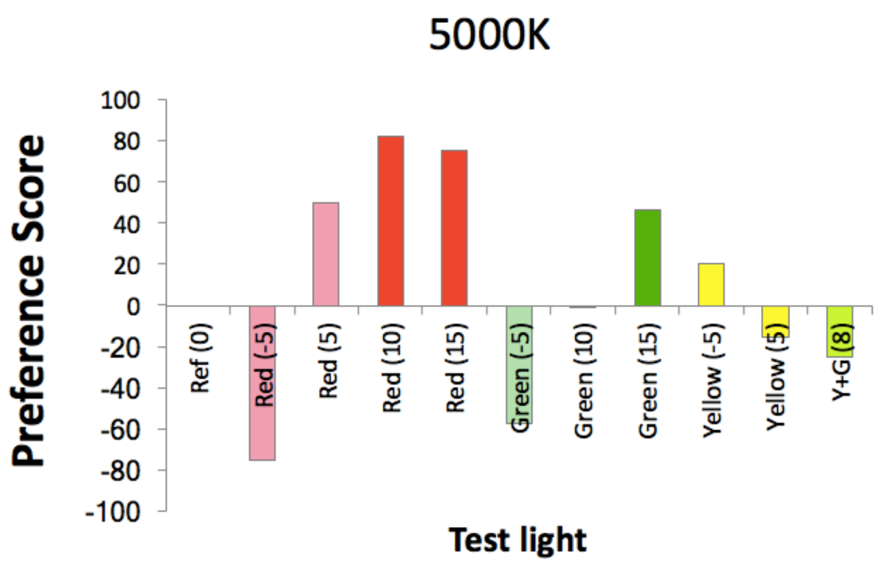
z_{ij} is the degree of preference of light i over light j in the scale from negative (disliked) to positive (liked).

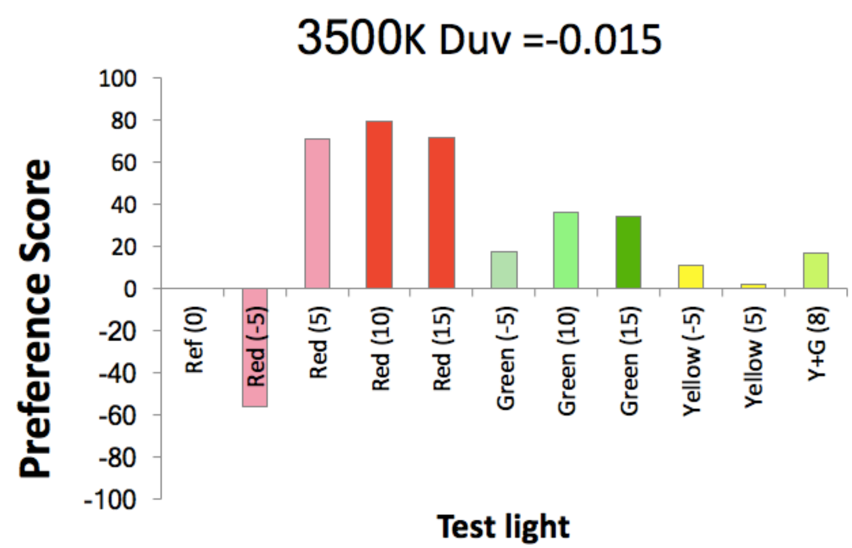
j \ *i*	1 (Ref)	2	3	4	5	6	7	8	9	10	11
	3) Z-score										
1	0.00	-1.10	1.21	0.75	0.91	-0.47	-0.11	0.83	-0.60	0.60	0.54
2	1.10	0.00	1.69	1.00	0.91	0.91	0.23	0.67	0.17	1.10	1.34
3	-1.21	-1.69	0.00	0.60	0.23	-0.83	-0.54	-1.10	-1.69	-0.83	-0.11
4	-0.75	-1.00	-0.60	0.00	0.41	-0.54	-0.60	-0.29	-1.10	-0.75	-0.47
5	-0.91	-0.91	-0.23	-0.41	0.00	-0.83	-0.47	-0.60	-0.91	-0.47	-0.47
6	0.47	-0.91	0.83	0.54	0.83	0.00	0.75	1.10	-0.35	1.34	1.69
7	0.11	-0.23	0.54	0.60	0.47	-0.75	0.00	0.06	-0.41	-0.11	1.21
8	-0.83	-0.67	1.10	0.29	0.60	-1.10	-0.06	0.00	-0.29	-0.06	0.23
9	0.60	-0.17	1.69	1.10	0.91	0.35	0.41	0.29	0.00	0.67	0.83
10	-0.60	-1.10	0.83	0.75	0.47	-1.34	0.11	0.06	-0.67	0.00	0.60
11	-0.54	-1.34	0.11	0.47	0.47	-1.69	-1.21	-0.23	-0.83	-0.60	0.00
Average $Z_{ave,i}$	**-0.23**	**-0.83**	**0.65**	**0.52**	**0.56**	**-0.57**	**-0.14**	**0.07**	**-0.61**	**0.08**	**0.49**
	3) Normalized z-score $Z_{norm,i}$										
Norm.	0.00	-0.60	0.88	0.75	0.80	-0.34	0.10	0.30	-0.38	0.31	0.72
	Preference score										
x 100	**0**	**-60**	**88**	**75**	**80**	**-34**	**10**	**30**	**-38**	**31**	**72**

2016 Results (fruits and vegetables)

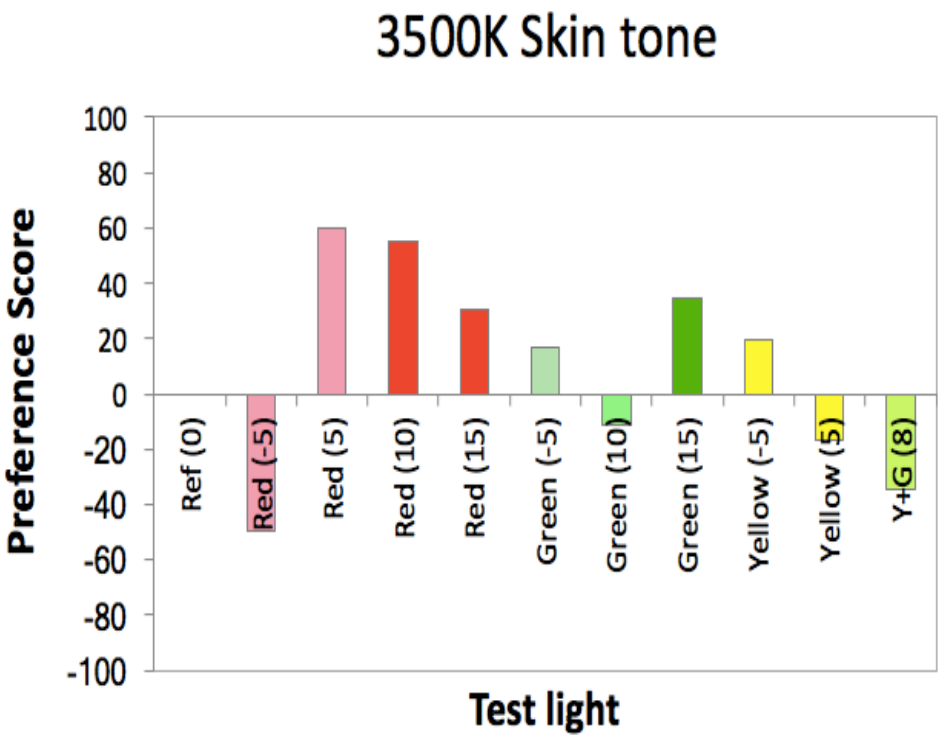


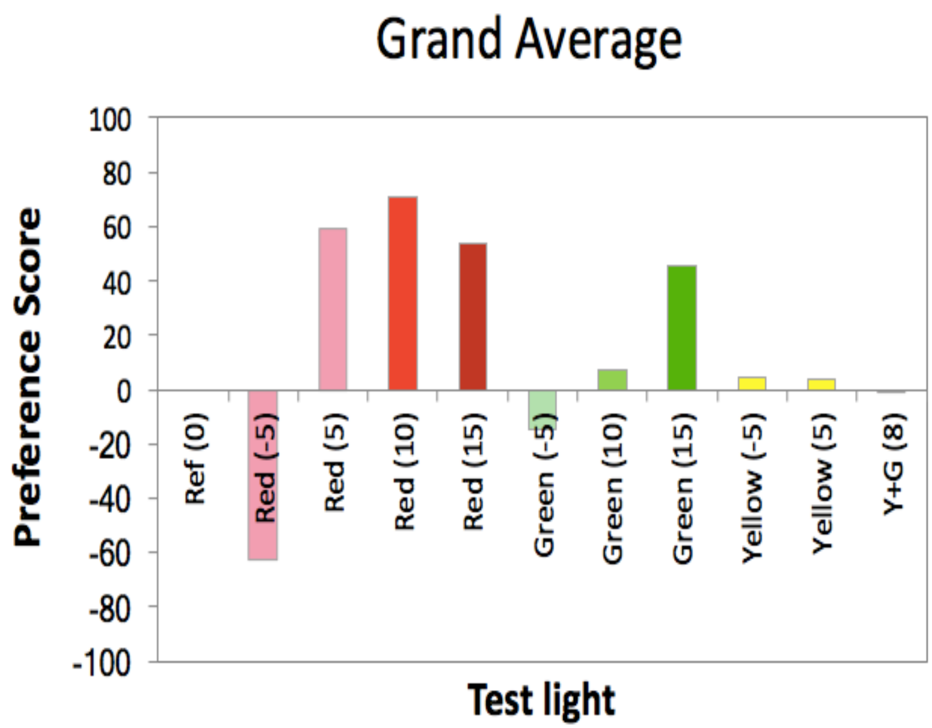




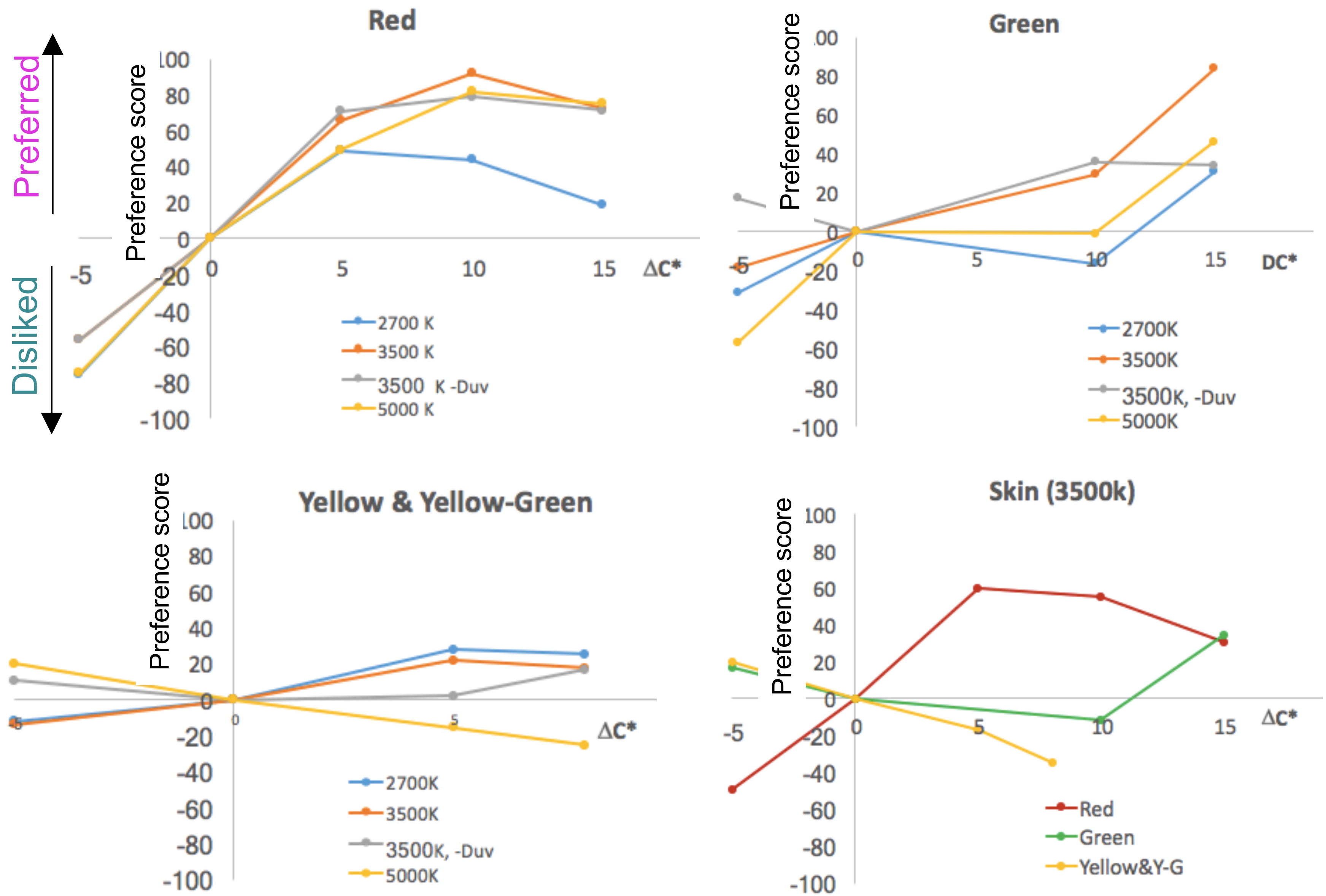


2016 Results (Skin, Average)





2016 Results as a function of chroma increase



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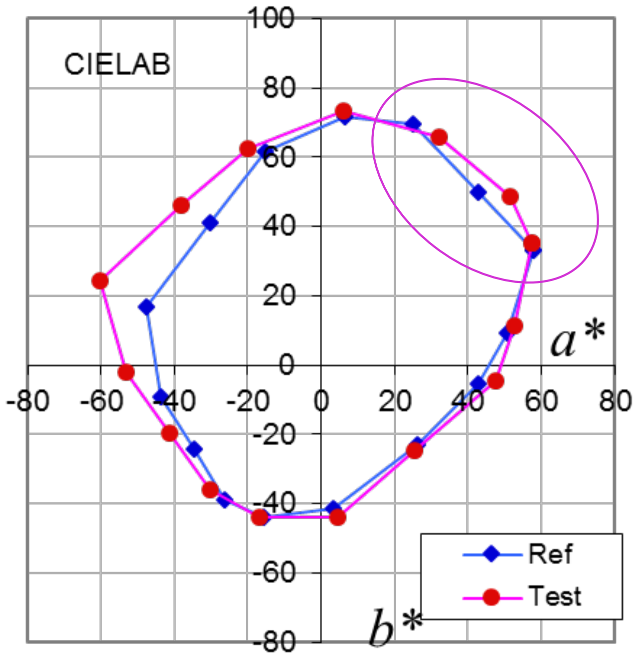
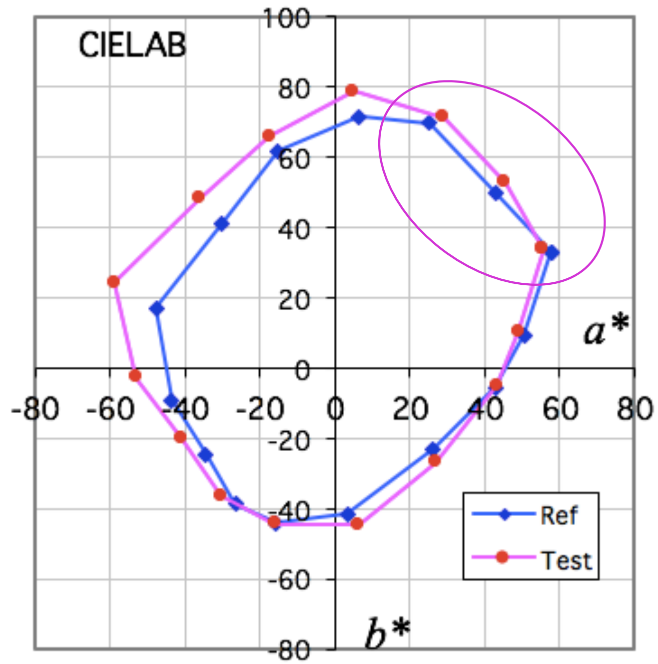
Improving gamut shape in 2017

2016



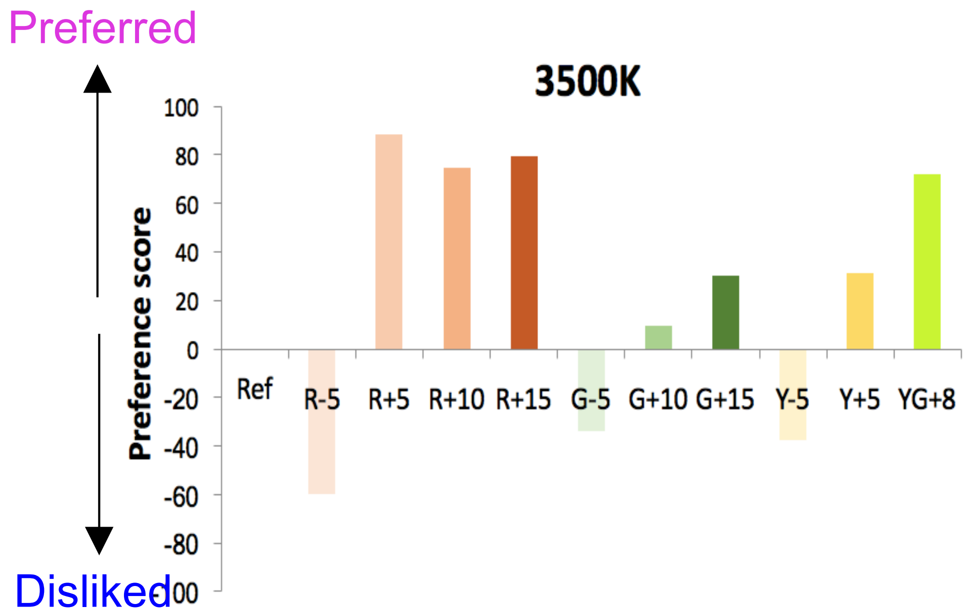
Green ΔC^*_{ab}=15

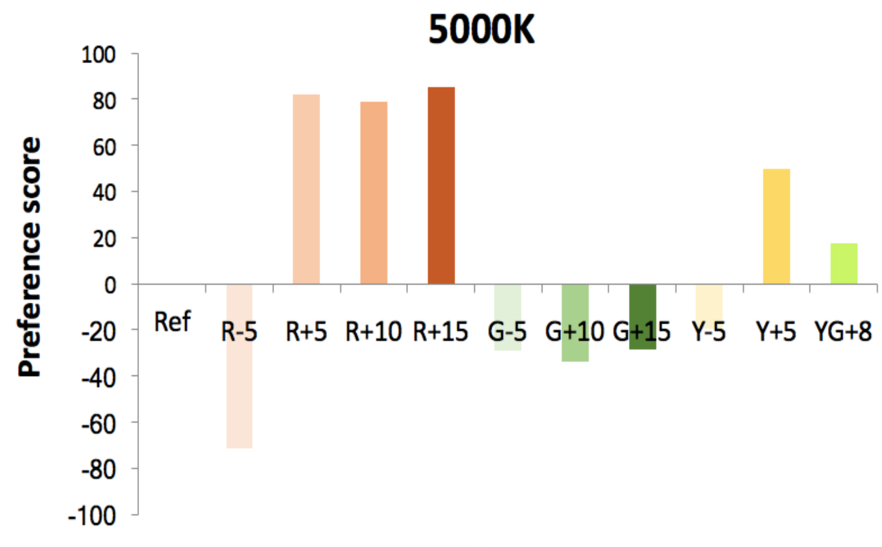
2017

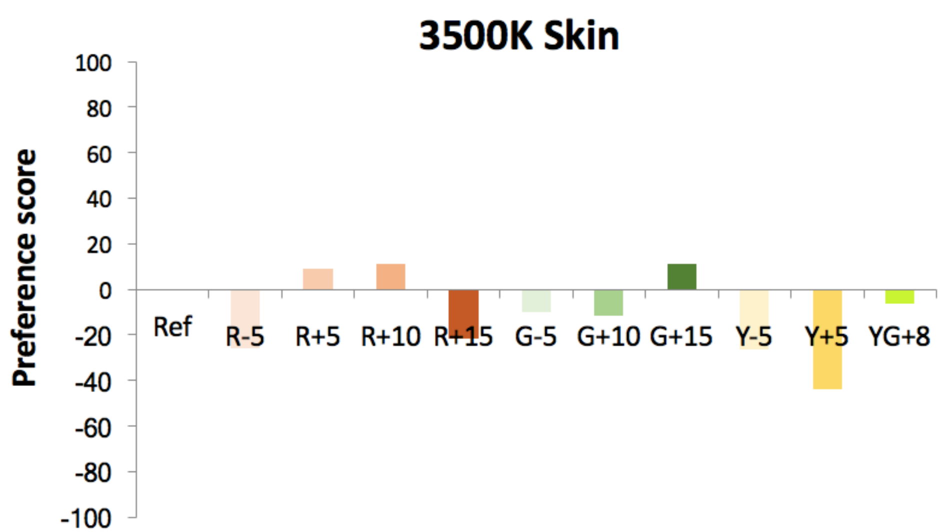


Green ΔC^*_{ab}=15

2017 Results

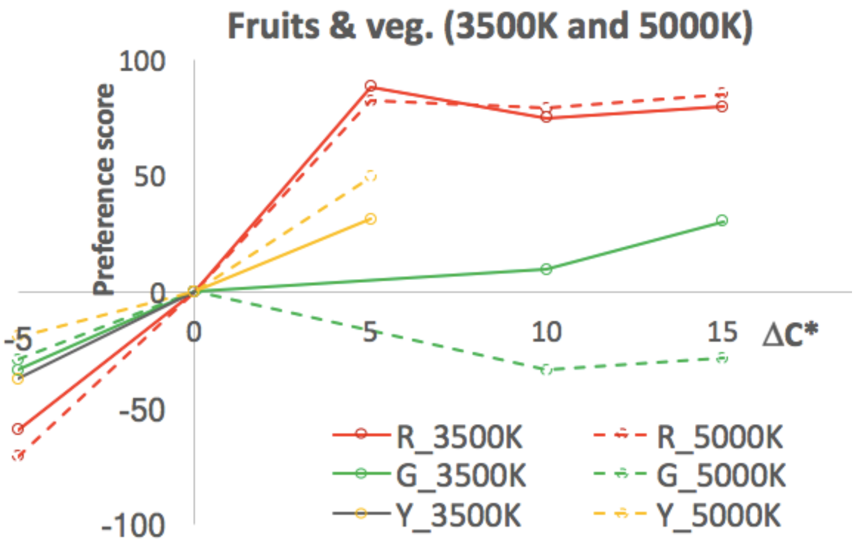


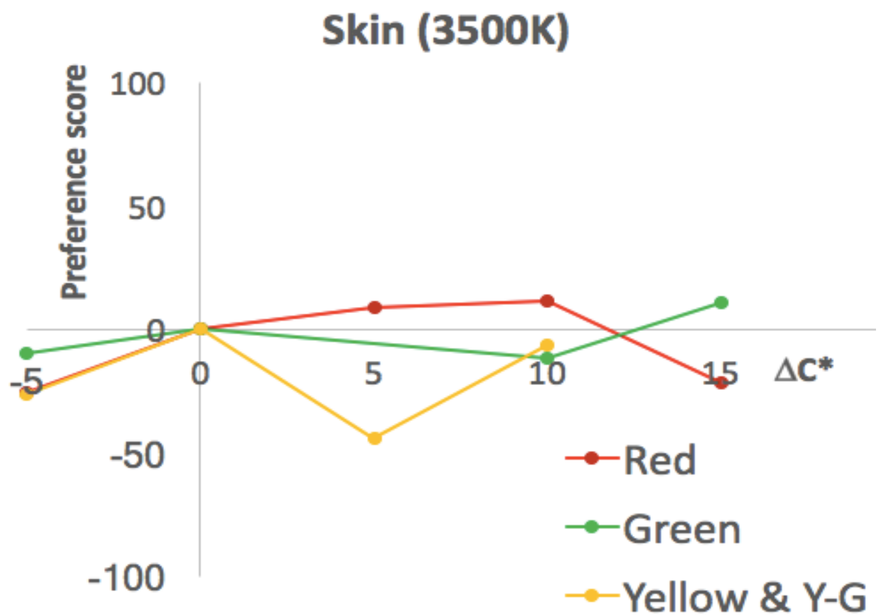




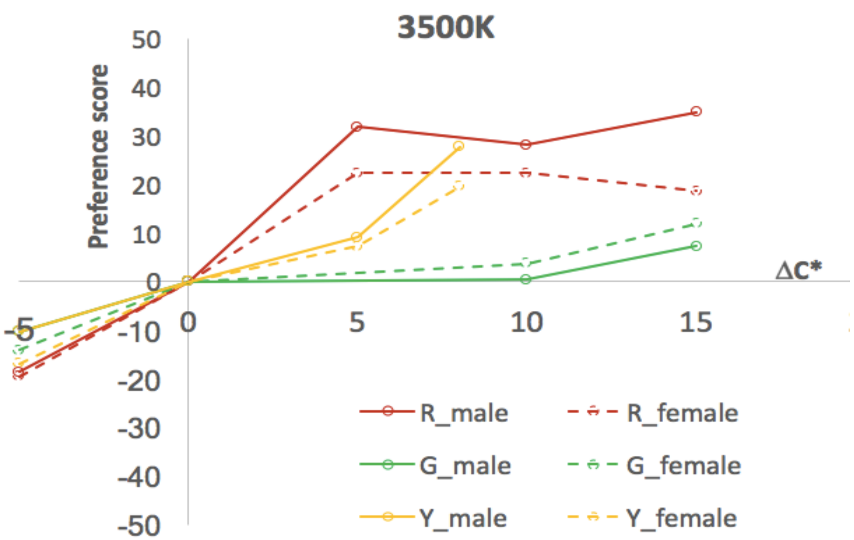
Red is dominant.

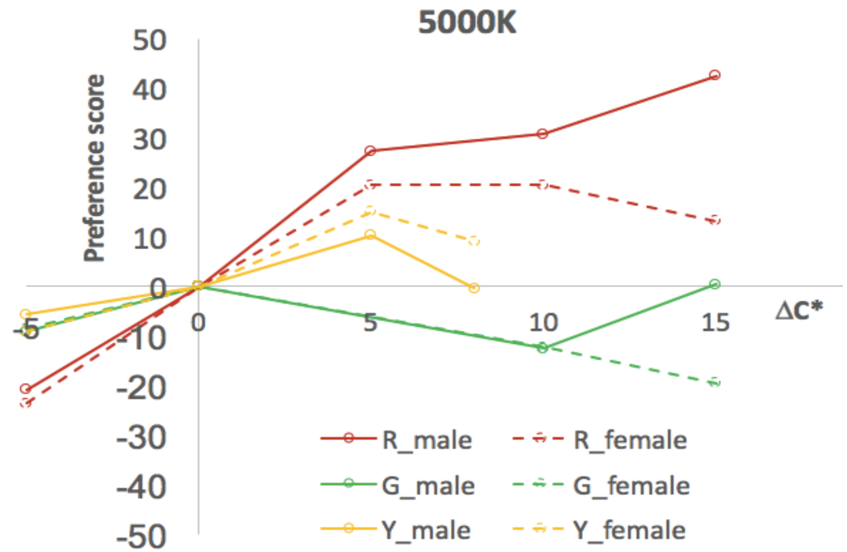
2017 Results as a function of chroma increase

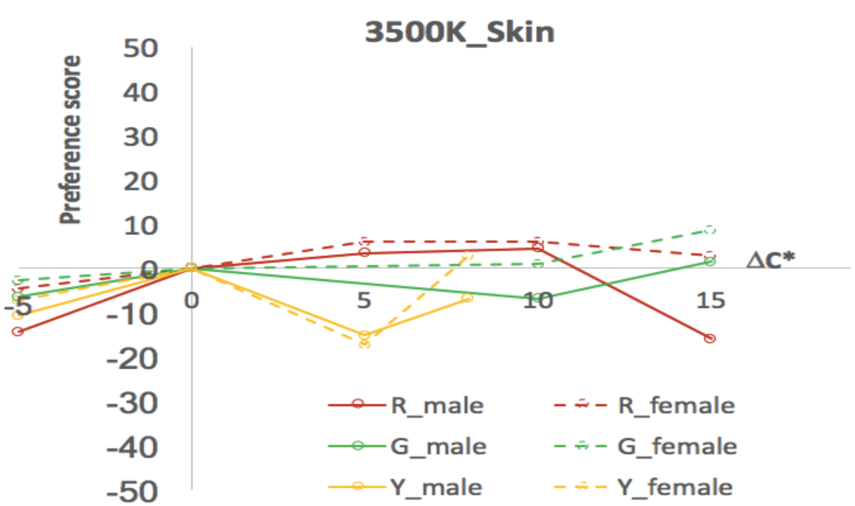




2017 Results (male / female)







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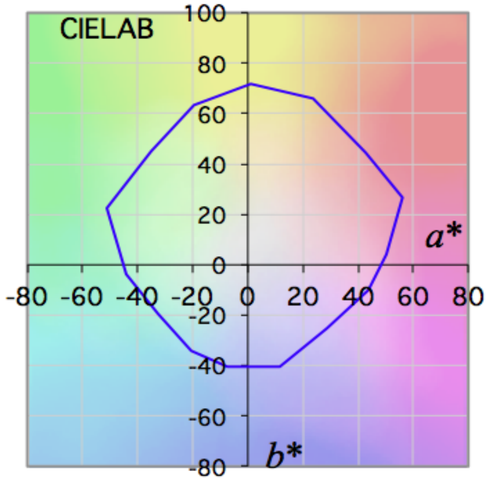
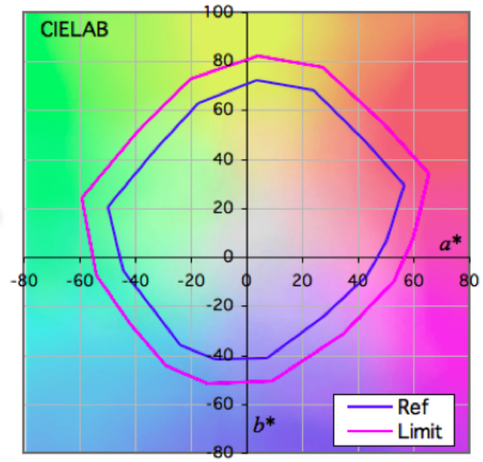
Toward future development of a color quality preference metric

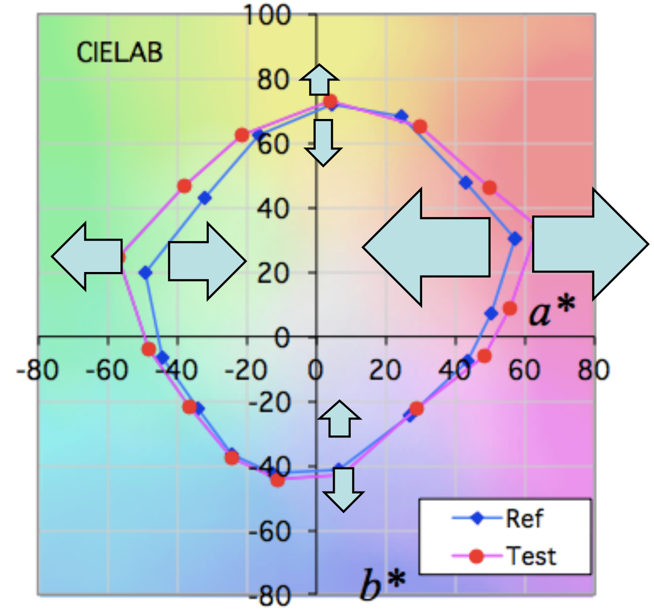
Fidelity reference Illuminant (blackbody/daylight)

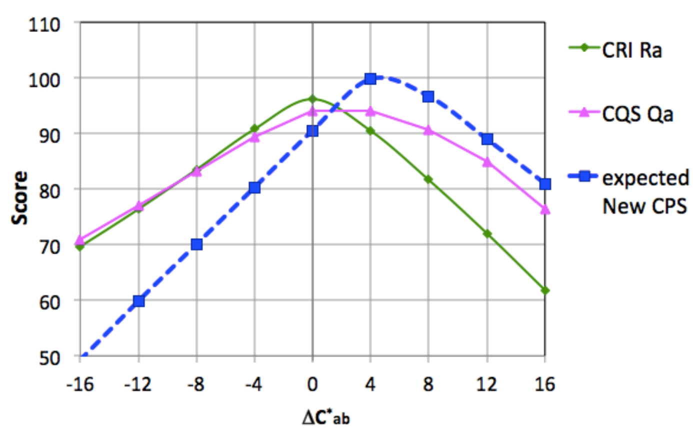


Preference reference Illuminant



Modeling (different weights for different hue)





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CIE Research Strategy

(August 216)

Top Priority Topics

1. Recommendation for Healthful Lighting and Non-Visual Effects of Light **(D3, D6, D2)**
2. **Color quality of LED light sources related to Perception and Preference (D1, D3)**
3. Integrated Glare Metric for various lighting applications (D3, D4, D5)
4. New
   Rad
5. Ada
6. App
7. Visu
8. Sup
9. Metrology for advanced photometric and radiometric devices **(D2)**
10. Reproduction and Measurement of 3D object **(D8)**

The overall objective of the research topic is to develop indices for colour quality other than colour fidelity, especially those related to general colour preference, which is the perceived or subjective judgement of colour rendering (e.g. for naturalness).

Summary

- It is verified that chroma increase in red is the dominant factor in preference.
- Green requires large increase in chroma for preference effect.
- Yellow increase has much less effects for preference.
- A model for color quality preference is being developed based on these results, toward developing a general color preference metric proposal.
- Further studies needed for differences by gender, age, ethnic groups, etc.